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Theoretical and practical considerations for teaching diagnostic electronic-nose technologies to clinical laboratory technicians

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Abstract

The rapid development of new electronic technologies and instruments, utilized to perform many current clinical operations in the biomedical field, is changing the way medical health care is delivered to patients. The majority of test results from laboratory analyses, performed with these analytical instruments often prior to clinical examinations, are frequently used for management decisions pertaining to patient care rather than as aids to diagnosis. The introduction of novel, improved electronic methods and portable tools for diagnosing diseases and for administering treatments has required continuous retraining of laboratory technicians for routine clinical operations and point-of-care testing. Continuous education and competency of clinical laboratory technicians in the proper use of these new healthcare tools, such as electronic-nose (e-nose) devices, is required to obtain the highest quality information possible for management decisions and to develop efficient treatments for patients. E-nose devices often provide more accurate and timely information than conventional chemical methods. Electronic-nose devices of various types and operational technologies are beginning to be used at increasing frequency in hospitals and clinical settings because of the capability of these instruments to provide rapid, accurate information of a patient's physiological state and health in real-time, eliminating the need for time-consuming chemical tests. E-nose devices are ideal instruments for the detection and diagnosis of disease and for the rapid recognition (sensing) of chemical-bioindicator compounds as indicators of disease within human fluid and tissue samples sent to diagnostic clinical laboratories for analysis. The proper training of technicians in the effective use of e-nose instruments for healthcare applications requires thorough understanding of the theoretical workings of e-nose devices and practical knowledge of operational methodologies that must be followed in order to effectively use e-nose devices to obtain the essential patient information required by medical doctors to make accurate diagnoses and administer rapid effective treatments. This paper provides a review of the most important theoretical and practical considerations to include in the development of training courses to teach clinical laboratory technicians how to properly operate e-nose devices for effective clinical analyses.

Keywords: Analytical instrument operation, Clinical technicians, E-nose methods, Teaching research methods, Science education

1. Introduction

The field of clinical chemistry developed as a branch of pathology, but has since expanded to such a degree that now it is considered an applied scientific discipline in its own right [1]. The processing and analysis of human samples collected in clinical laboratories for diagnostic purposes depends on the skills and abilities of its technical personnel that must be sufficiently trained to carry out daily laboratory tests. The basic training programs developed for technical laboratory personnel include such important disciplines as analytical chemistry, biochemistry, statistics,

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physiology, pathology, engineering, immunology, radiochemistry, and toxicology among other specialized fields. Appropriate information from these various interdisciplinary subjects must be thoroughly integrated into technical training programs with the correct balance and detail in order to develop didactic instruction and teaching systems that provide sufficient details to give technical staff the necessary practical and applied knowledge required for analytical operations in the modern clinical laboratory.

Analytical clinical techniques based on electronic detectors are becoming increasingly important in the diagnosis of human diseases. Chemical biomarkers, as indicators of specific diseases, often can be detected much more quickly using electronic-nose (e-nose) devices than by conventional cultural or expensive chemical techniques, providing means for obtaining rapid and often more accurate diagnoses, and thus more timely and effective treatments for patients. E-nose devices are versatile and ideal electronic tools to detect the presence of specific chemical biomarkers of disease because they are capable of sensing a wide range of volatile organic compounds (VOCs) produced as a result of pathogenesis, aberrant metabolic pathways produced by microbial disease-causing agents, or diseases caused by genetic or metabolic disorders [2]. Some of the most promising recent clinical applications being developed using electronic-nose technologies have been for the early detection and diagnosis of diseases that can be detected by the presence of aberrant VOCs in human breath or expired air. The use of VOC biomarkers in microbial disease diagnosis will likely become increasingly important in the future as more information becomes available of new biomarker indicator compounds associated with specific diseases, and as biomarker detection with electronic noses becomes routine in clinical practice [3]. A wide range of e-nose instrument types have facilitated the creation of many new categories of medical applications that take advantage of the unique strengths and advantages of specific e-nose sensor types and arrays of different e-nose instruments [4]. One of the major advantages of e-nose technologies over conventional wet-chemistry techniques is the capability of rapidly detecting and identifying specific mixtures of VOCs in laboratory samples, indicative of diagnostic physiological or pathological conditions of the patient, often in significantly shorter time. This advantage allows the patient to be supplied with an appropriate treatment much quicker, allowing a more rapid recovery to a healthful condition. E-noses also can be used in combination with other electronic sensing equipment and medical instruments to generate synergistic information useful for patient treatment and management. E-nose information may be used to confirm physiological states or functions in patients that are identified in pre-scanning and preliminary assessments of patient conditions during initial examinations.

The training of clinical laboratory technicians in the proper operation, maintenance, and uses of electronic-nose instruments and devices, used as diagnostic equipment in disease detection, is becoming increasingly important as these new electronic gas-detection devices become more commonly used for routine clinical applications in the analysis of human fluid and tissue samples. Consequently, the development of didactic methods for teaching e-nose operational methodologies to clinical laboratory technicians by various methods, including instructional demonstrations, has become essential in order for e-nose instruments to be integrated into routine clinical practice through use in daily operations. In order for clinical technologists to develop instructional methods and effectively teach e-nose operational methods to clinical laboratory technicians, they must acquire technology-specific knowledge and find ways to effectively use specialized didactic techniques and multiple instructional approaches to thoroughly cover all of the skill and knowledge requirements in their training course. Certain types of e-nose operational skills are more effectively taught using certain types of instructional approaches whereas other skills are often better taught with other approaches. Using multiple instructional approaches often speeds up the training process by providing opportunities for students to practice skills in informal, low-stress settings outside of instructor-supervised training sessions.

This paper is a review of some of the more important practical and theoretical considerations to take into account when preparing educational materials and systems for didactic demonstrations and training of clinical laboratory technicians in the proper use of electronic-nose technologies for various biomedical and clinical applications. It provides a summary of the scope of knowledge and expertise required of technical staff in clinical laboratories, including prerequisite knowledge needed prior to specialized training in the effective operation of diagnostic electronic-detection devices, specifically electronic-nose instruments. Furthermore, various methods and resources available for e-nose instrument training are provided to allow for the development of structured and multistage training programs, integrating different teaching strategies and approaches aimed at minimizing cost and improving efficiency in the training process.

2. Prerequisite training requirements for clinical laboratory technicians

Clinical laboratory technicians, also known as medical technicians, medical laboratory technicians, and clinical laboratory technologists, perform a variety of technical functions in the clinical laboratory. All of these job titles refer to individuals who are responsible for performing very specific routine tasks in the laboratory that aid in the detection, diagnosis, and treatment of disease. The important analytical tests conducted by laboratory technicians on human-derived fluid or tissue samples are needed to generate information on the physiological or pathological condition of patients with various types of ailments, diseases or disorders or to determine their state of physical health compared to normal or average ranges of human chemical parameters. Most clinical laboratory technicians work in hospitals, research institutes, clinics, or commercial medical laboratories that run tests for doctors and hospitals on a fee basis. Clinical laboratory technicians generally are supervised by clinical laboratory technologists, physicians, or pathologists. The skills and knowledge requirements of clinical laboratory technicians has undergone profound changes in recent decades as a consequence of many new scientific discoveries and technological advancements in analytical laboratory techniques resulting from fundamental increases in knowledge of anomalous chemical attributes found to be associated with specific human diseases. To take advantage of these technological advancements in the science of medicine, laboratory technologists must continue to rapidly evolve and advance their repertoire of skills in the use of these new improved laboratory techniques and analytical instruments developed for various healthcare screenings and disease detections. The rapidly evolving field of medical diagnostics will continue to be a major challenge for laboratory technicians who must be willing to continuously update their knowledge and skills to remain competent and effective in the ever-changing clinical laboratory environment. The following sections provide an overview of some of the key variables affecting the training needs of clinical laboratory technicians and prerequisite educational requirements necessary for further training in the use of advanced electronic-detection devices used for routine laboratory analyses, particularly electronic-nose devices that are becoming more prevalent as diagnostic tools used in the clinical laboratory.

2.1. Variables affecting technician training needs

The broad range and complexity of instruments and protocols used in modern medical diagnostic laboratories has demanded significant changes in academic curricula and educational requirements in order for technicians to be able to perform well at multiple stations within a fully functional comprehensive clinical laboratory. However, the range and breadth of skills required can vary considerably depending on a number of significant variables associated with geographic locations, demographics, and the complexity of laboratory facilities associated with various types of medical institutions involved in medical diagnostic testing. Some specific factors related to educational requirements that affect laboratory technologists and technicians include: 1) required curricula and training levels that differ among nations, 2) career opportunities within the profession that vary considerably based on skill levels, and 3) employment opportunities over a technicians lifetime may be quite difficult due to the necessity of maintaining high skill levels in current, continuously updated technologies [5].

There are important national differences in the educational requirements of various medical institutions. Clinical laboratories in the United States employ technical staff at two distinct levels, the more educated technologists and the less educated technicians. Even at a U.S. university, there may be only one physician director whereas in Europe there is greater use of doctoral-level personnel for daily operations. Technologists in Japan come from a medical or pharmaceutical educational pathway whereas the education of technologists in Europe differs from country to country [5]. European authorities have tried to produce regulations governing medical education credentials in order to achieve equivalency and standardization of educational requirements in Europe, as well as in the United States and other industrialized nations, through increased recognition and use of national and international educational certificates. The ultimate hope was to produce a universally portable certification system allowing for global licensure and accreditation [6].

Clinical laboratories can differ significantly in organization, staff structure, levels of staff skills and competency, and range of tests performed. For example, the laboratory setting and medical conditions in developed countries can vary profoundly with those in second- and third-world countries. The same high level of professional excellence and technological utilization is not universally applicable. In 1972, the World Health Organization (WHO) defined four levels of technical personnel in the clinical laboratory, ranging from Level A for senior or supervisory technologists to Level C and D who are assistant technicians who only perform simple analytical procedures [7]. Technologists in the intermediate Level B category conduct more complicated laboratory procedures and may help train lower-level technicians. Thus, the role of technical personnel in a clinical laboratory of a complex tertiary-care hospital of a large metropolitan area may differ significantly from a primary care laboratory serving a rural hospital. The intensity of demand for services and breadth of tests provided also can vary considerably with the level of sophistication of clinical institutions. Consequently, the intensity of demands and pressure on technologists to develop skills with new scientific developments can vary depending on whether they are expected to rotate through different work stations and laboratory tasks or are allowed to specialized in specific procedures as when a laboratory policy is employed involving a division of labor among available technologists and technicians.

2.2. Basic technical training requirements

The basic training necessary for laboratory technicians to achieve expertise and qualifications for a Level B technician, based on WHO criteria, can be undertaken in one of three ways, including either 1) full-time institutional training, 2) wholly laboratory-based training, or 3) via a combined system containing both theory and basic practical work at a technical college and training at a recognized laboratory by qualified teaching personnel for a specific period of time [1]. These requirements generally involve at least ten years of secondary education. National requirements usually recommend a total of 3-4 years of training for medical laboratory technicians depending on the country. The duration of training varies between countries depending on the particular job-entry requirements, and level and type of competence required. All training must be necessarily validated by an examination or some other form of acceptable assessment by the granting of a certificate of competence.

A general framework for a training program for technical staff at a clinical laboratory should include the following basic elements including a high standard of analytical competence, understanding of laboratory instrumentation and ability to operate and maintain them, understanding principles of basic sciences and mathematics, ability to interpret analytical data, communicate effectively with clinical personnel, teach and train junior personnel and take responsibility for their performance, write coherent and precise documents, work effectively under pressure at any time of the day, have confidence in ones abilities, and have knowledge of the correct use of library facilities and computers for data entry and information retrieval [1]. Adequately trained laboratory technicians also should be capable of recording information with accuracy, precision, and complete honesty in order to maintain the integrity, confidence, and accountability of laboratory analyses.

2.3. Required laboratory technical skills

The required skill levels of clinical laboratory staff have gone through an historical evolution that has progressed from the on-the-job learning and training in the infancy of laboratory technology, to full-time institutionalized professional education [5]. Increasing educational requirements have been driven by advances in knowledge and technologies utilized in routine clinical analyses. As a consequence, education and training for technical laboratory staff has become a lifelong process as advanced professional skills must be updated continuously in order to integrate technological advancements through increased analytical competencies including abilities to process, analyze and interpret data, communicate analytical findings, and provide clinical summaries and sometimes conclusions to medical doctors and other higher-level diagnostic staff. These accretions of skills and duties for technical laboratory staff include the continuous development of new skills for operating novel analytical and diagnostic equipment such as electronic-nose devices used for the detection of disease and abnormal physiological conditions of patients.

Most routine laboratory procedures usually are learned by technician trainees through instruction from higher-level technologists by practical experience gained during in-service training. Learned general laboratory skills usually apply to all or most analyses and tests run in clinical laboratories. These skills are linked to sequential steps of activities and processes associated with most general clinical chemical analyses and protocols. The typical sequential pattern or flow of consecutive activities associated with most routine clinical test procedures include proper specimen collection, treatment and storage, reagent and apparatus preparation, analyzing the samples using specific procedures and chemical-detection instruments, data recording and processing, data manipulation and statistical analysis, and finally preparation of chemical analysis reports followed by diagnostic interpretations and recommendations of proper course of action for patient management and/or treatment based upon the test results. All of these steps, except perhaps the final steps, must be mastered by the laboratory technician for each type of test performed. The specific details and operational steps involved for each test can vary considerably, requiring constant practice to maintain proficiency and consistency of results. Sometimes trouble-shooting of protocols is required to find out why specific tests stop working. These steps involve techniques for assessing reagent quality and purity, evaluations of whether specific protocols were closely followed, and checking on internal standards to find the source of technical problems. Similar efforts must be performed if analytical instruments fail to perform correctly or get out of calibration.

2.4. Advanced laboratory technical skills

Technologists and clinical chemists with greater responsibility, knowledge and experience are expected to master some additional skills that affect the operational effectiveness and efficiency of the entire clinical laboratory. These higher-level technical skills include capabilities and understandings of laboratory and financial management, planning laboratory services, organization of laboratory activities and spatial structure (test stations), methods development and evaluation, maintenance of analytical equipment, internal quality control and quality assurance, data analysis and interpretation, instrument selections, conducting advanced training of technologists and technicians in instrument operations, developing improvements in methods and techniques, and preparing laboratory procedural manuals and case reports [8, 9].

Making decisions involving the selection of the most appropriate tests for specific types of sample analyses are very important key activities that higher-level technologists and chemists must do to assure that the high quality and effectiveness of all clinical laboratory services provided are maintained. These decisions often involve the physician director of the laboratory and require periodical evaluations of techniques to determine when obsolete tests should be phased out and new more effective tests should be utilized. The process of eliminating obsolete tests and introducing new tests into laboratory operations involves significant evaluation of new instrument capabilities and associated procedures to see if they are indeed more effective, efficient, and perhaps cheaper to perform than previous tests as well as technically within the capabilities of existing technical staff.

3. Laboratory technician training needs for electronic-nose instruments

There are a number of instrumental variables and gas-detection principles that affect the training needs and requirements for adequately instructing clinical technicians in the proper effective use of electronic-nose instruments for laboratory analyses. These instrument variables determine the operational procedures required for conducting chemical analysis using e-nose devices, and consequently, the necessary differences in teaching methods and course content that must be covered depending on the particular type of e-nose analytical instrument for which students will receive operational training.

3.1. Teaching electronic-nose operational procedures

E-nose instruments are not all alike in terms of instrumental procedures or ease of use (user-friendliness) due to significant differences in design, ergonomics, mechanisms and principles of operation. Thus, the training required for clinical technicians to competently operate e-nose devices can vary considerably according to modes of operation and the difficulty of procedures needed to effectively analyze samples. Some commonly-used e-nose technology types include conducting polymers (CP), metal-oxide semiconductor (MOS), quartz crystal microbalance (QCM), and surface acoustic waves (SAW) [4]. Also, laboratory-grade e-nose instruments behave and operate much differently from simple mobile application-specific e-noses. Laboratory-grade instruments generally are more expensive, complicated in operation, require extensive technical training (for operation, maintenance, and data-interpretation), and are highly versatile in terms of numbers and permutations of control settings that are possible (adjustable) which complicates repeatability (precision and accuracy) within the normal range needed for diagnostic testing. All of these problems have largely contributed to the failure of applying laboratory-grade e-nose instruments to practical clinical applications. As a result, many e-nose devices are being redesigned to limit the range of instrument-control settings and data outputs to simplify operations and data interpretations. This redesign has required developing cheaper, more specialized application-specific e-noses to reduce costs and facilitate use by technicians in routine clinical analyses. The simplification and specialization of e-nose instruments accordingly has made the process of teaching instrument operational procedures much easier.

3.2. Differences in e-nose operational procedures

Electronic-nose devices of numerous types operate by a wide range of different gas-detection principles. The most common e-nose methods utilize transduction principles based on electrical measurements, including changes in current, voltage, resistance or impedance, electrical fields and oscillation frequency [4]. Other e-nose types measure mass changes, temperature changes or heat generation. Optical sensors measure the modulation of light properties or characteristics such as changes in light absorbance, polarization, fluorescence, optical layer thickness, color or wavelength (colorimetric) and other optical properties. Metal-oxide (MOS) gas sensors, the most widely used class of gas sensors, operate at high temperatures ranging from about 300 °C to 550 °C requiring high power consumption. The sorption of gas molecules to MOS sensors provoke changes in conductivity brought about by combustion reactions with oxygen species on the surface of the metal-oxide particles. Acoustic sensors, such as quartz crystal microbalance (QMB) and surface & bulk acoustic wave (SAW, BAW) sensors have organic or inorganic film layers that measure mass changes when chemical analytes are adsorbed to the sensor surface causing shifts in the vibration frequency of crystals. Calorimetric sensors measure temperature or heat change resulting from chemical reactions with the analytes. Colorimetric sensors utilize organic dyes that have color changes in response to analytes that can be measured via light absorbance like a spectrophotometer. Conducting polymer (CP) e-noses have polymers within individual sensors that are capable of conducting electricity, allowing analytes to be measured by changes in electrical resistance across sensor paths. Electrochemical sensors have solid or liquid electrolytes that measure current or voltage changes. Fluorescence e-nose sensors detect fluorescent-light emissions whereas infrared sensors measure infrared-radiation light absorption. Optical sensors contain a light-sensitive photodiode sensor that detects light modulation or optical changes. The vast differences in detection principles utilized in different e-nose instrument types largely determines the types of chemicals that can be detected as a result of differences in the chemical properties and characteristics of analytes (from different classes of chemical compounds) that may be present in clinical laboratory samples. Consequently, the type of e-nose that is employed for the detection of particular classes of chemical analytes that may be present in clinical laboratory samples will largely be determined by the type of target compounds that are being detected by the analysis.

Electronic-nose devices that are capable of detecting the presence of volatile organic compounds (VOCs) are most useful for the majority of clinical analyses because organic chemicals make up the vast majority of analytes that are targeted for detection by most clinical laboratory tests. E-noses sensitive to VOCs also are useful for detecting human hormones, toxins, and metabolites, but other e-nose types may not be capable of detecting heavy metals or certain inorganic compounds although there are many e-nose devices that are capable of detecting inorganic compounds in both aqueous and air samples collected from the headspace above clinical samples, such as excretory blood and body fluids or excised tissue specimens.

The procedures and processes utilized in setting up e-nose detection methods for clinical laboratory analysis generally follow basically the same overall sequence of steps regardless of the e-nose used. Of course, some exceptions exist depending on whether aroma-reference libraries are used. A generic model flow chart showing the processes involved in the operational procedures used for most electronic-nose devices is illustrated in Figure 1.

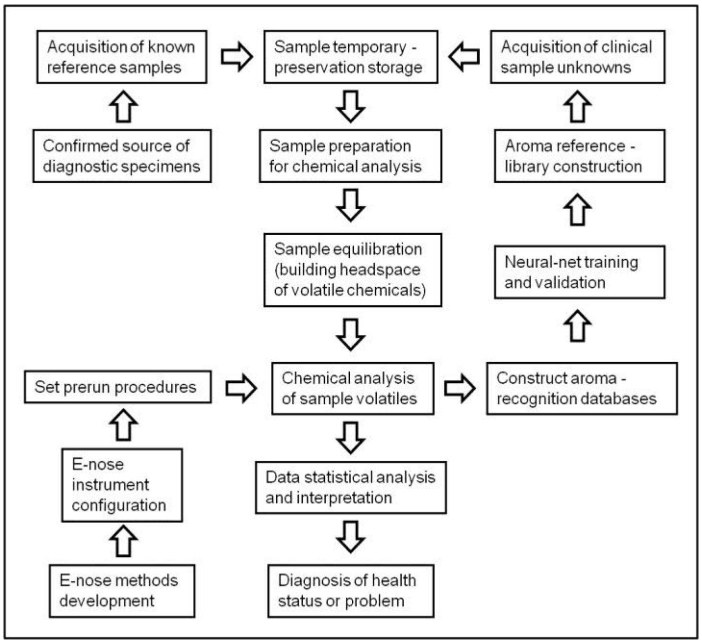

Figure 1. Electronic-nose (e-nose) general operational-procedures flowchart

This flow chart, listing the sequence of steps involved in the detection and analysis of specific target analytes within clinical samples, may be used as a basis for setting up and developing didactic training modules for teaching different e-nose operational procedures (in more detail) which are associated with each required step in the analysis process. The flowchart divides the e-nose sample-analysis procedure into four main components, or procedural processes, that lead up to final sample analysis and diagnosis based on interpretation of sample results. These four processes include: 1) methods for the acquisition and preparation of known diagnostic reference samples (or standards) used in developing aroma reference databases and libraries, 2) specialized methods development for the specific type of analytes being detected for particular clinical tests, 3) construction of aroma reference databases and libraries specific to particular applications (individual clinical tests) and 4) final chemical analysis procedures, data analysis, and diagnosis derived from analysis test results. The instructor responsible for teaching e-nose procedural and operational methods should address each operational process individually due to the detail involved and the technical information and idiosyncrasies associated with particular e-nose types and different clinical tests. Thus, each one of these procedures should be given a dedicated teaching module to allow the trainee the opportunity to individually master the various skills associated with each process. This approach will result in more thorough training and produce training results of higher quality and technical competence in laboratory technicians. Differences in the analytical procedures used in the operation of electronic chemical analysis instruments ultimate depends on the types of samples to be run, the specific analytes to be detected, and the type of e-nose devices being used in the analysis.

3.3. Quality control and analytical methods assessment

New clinical methods and instruments are continually being developed in an attempt to improve on existing laboratory sample analysis by producing more rapid and definitive results for clinical diagnoses. Most new tests are developed for specific applications. However, new clinical tests become practical only if they provide new information useful for patient management. Good analytical performance does not necessarily ensure that a new test is going to have real clinical value with any advantages over existing tests [10]. Thus, new diagnostic tests should be subject to methods assessment in clinical trials to determine their diagnostic usefulness before being accepted into routine clinical use. Methods assessment involves comparing the analytical results of the new methods to existing routine clinical tests in terms of analytical limits, precision, accuracy, sensitivity, and specificity. A good methods-assessment trial should be well-designed and carefully conducted to compare test results on the basis of their true-positive rates with appropriate decision levels so that the tests under comparison have the same false-positive rate [10]. A diagnostic trial of a new prospective analytical method should be subject to a Phase III trial (designed as a blind, controlled, real-time study) to evaluate the capability of the test to answer a specific clinical question. Other criteria used for assessing the usefulness of new analytical methods or instruments include capital costs, practicability, dependability, types of specimens (samples) required, sample throughput time, sampling rate, analysis information provided, standards and reagent requirements, range of compatible methods (designed for), space and service requirements, special training requirements for operation, and operational-safety hazards [11, 12]. Laboratory technicians must be taught the process of new-methods assessment so that they have a good theoretical knowledge of the methods-evaluation trial process for new tests which are designed differently from normal clinical tests due to the need to compare the quality and usefulness of analytical test results.

Electronic-nose devices sometimes are used in clinical laboratories for monitoring quality assurance-quality control (QA-QC) of analytical methods to maintain highly consistent quality of precision, accuracy and efficiency of laboratory conditions and to assure product and reagent uniformity used in laboratory procedures, analyses and tests. However, no system for monitoring QC is likely to improve a method that is fundamentally unsound [13]. E-nose instruments might also be used as a rapid means of checking on the accuracy of other clinical test results in the laboratory. Rapid confirmation of test results increases the reliability of the results to assure that prescribed treatments are effective in addressing the specific problem identified by the diagnosis. Technical staff in the clinical laboratory should be well aware of e-nose applications useful for confirming clinical test results obtained with other analytical instruments.

4. Teaching methods for e-nose operational training

A variety of didactic methods and systems are available to facilitate the often complicated process of training clinical laboratory technicians in the proper operation of e-nose instruments to ultimately produce rapid and accurate laboratory sample analyses. Effective and useful teaching tools range from interactive instructional methods used by preceptors for teaching ambulatory care diagnostic skills to all levels of residents and medical students to various virtual interactive software aids and eventually live instructional sessions and certifications with real instruments.

Some important forms of training involved in a comprehensive medical training program for technical staff of clinical laboratories include formal lectures and practical training classes, in-house training, tutorials and seminars, and attendance of scientific meetings to stay abreast of new emerging technologies, followed by additional specific training as new analytical instruments are utilized [1]. Specific categories of teaching methods useful for clinical laboratory technicians include interactive methods, use of procedural manuals, virtual laboratories, remote access laboratories, virtual measurement systems, and live- instrument instruction which are discussed in greater detail in the following sections.

4.1. Interactive teaching methods

Specific training of laboratory technologists and medical preceptors in educational methods is essential to make sure that the teaching methods used are both effective and efficient in achieving competent training of technical personnel in the clinical laboratory, including laboratory technicians [14]. Some of the most useful teaching techniques developed for students working in medical clinics have been developed for ambulatory care teaching (ACT). ACT methods have been utilized primarily to teach nurses and medical students, but also offer some very useful and techniques for teaching clinical laboratory technicians in the detailed and sometimes difficult procedures for conducting laboratory analyses of human samples using various analytical equipment such as electronic-detection instruments. Training of clinical teachers responsible for teaching clinical laboratory techniques can be significantly improved using some of these methods adapted from ACT methods. Several of these ACT teaching methods are described in the following discussion.

Medical and nurse preceptors are essential key providers of clinical education for nursing and medical students [15]. Teaching techniques utilized by nursing preceptors for nursing students provide some teaching strategies that are also useful for clinical laboratory technicians because they help the student to develop clinical competence and confidence by maximizing learning opportunities. The origins of teaching theories most commonly used with the preceptor-teaching model today have developed out of a scheme described by Koen and Vivian in 1980 [16] that identifies discrete communication and teaching behaviors to assist clinical educators in improving specific teaching skills. They defined five teaching role modes including conceptualization, problem solving, teacher-learner relations, feedback, and role modeling-scholarship that were used to categorize 18 clinical teaching behaviors referred to as “microskills”. Use of the term microskills has become well utilized in medical science literature. Some of these microskills were used by Neher et al. [17] to create the Five Step Microskills Model of Clinical Teaching, now referred to as the One Minute Preceptor (OMP) [18]. The OMP technique was originally developed for use in medical education with family medical physicians [15]. The OMP method was not intended to replace other clinical teaching methods, but to increase the frequency and quality of teaching. The OMP method recently was modified for nursing by Bott et al. [15] and renamed the Five Minute Preceptor (FMP). The FMP was designed to stimulate the student to process information from a clinical experience, provide some interpretation and judgments based on reflection, display knowledge about the subject at hand, assess student learning needs and knowledge gaps, provide feedback to reinforce positives, identify student strengths and competencies, and correct errors and misinterpretations. Another teaching technique, named as an acronym for the action words Summarize Narrow Analyze Probe Plan and Select (SNAPPS), involves discussions between preceptors and students. SNAPPS is well suited for clinical medical education because of its medical focus on patient-case presentation and diagnosis to facilitate expression of clinical reasoning and uncertainties [19]. The SNAPPS technique attempts to address the main goals of clinical teaching which are to assess the student’s reasoning skills, strengthen their development, and provide opportunities for practice and feedback. Feedback is essential to prevent mistakes in a student’s performance from going uncorrected and to reinforce good performance to assure that clinical competence is achieved [20]. Overcoming the lack of feedback is one of the most persistent and difficult problems in clinical education [14]. Both the OMP and FMP techniques provide means and opportunities for a higher-level laboratory technologist to teach laboratory methods and protocols as well as analytical-instrument operational techniques to clinical technicians. Various studies have analyzed the components and effectiveness of these teaching techniques to find ways to further improve and refine the methods to achieve even more effective and efficient teaching results and training competencies in technical clinical personnel [21-30].

4.2. Procedural manuals for specific e-nose instruments

Laboratory procedural manuals play a crucial role in the education and training of students and technical staff that operate and maintain the production of high quality results in the clinical laboratory [31]. Procedural manuals are required because changes in methods used in the laboratory may lead to a reduction in quality of the analytical results produced or a reduction in the throughput capacity of the laboratory. Some countries have legislative requirements that mandate the availability of comprehensive instructions for analytical methods used in clinical laboratories.

Procedural manuals should contain detailed information on all aspects of every analytical test performed in the laboratory. This aim ensures that consistent quality and quantity of analytical results are produced on a time-monitored basis. Laboratory procedural manuals should contain full information on each analytical test including the following categories of information: 1) clinical indications for a test, 2) specimen requirements, collection procedures, required storage conditions, and disposal procedures, 3) principles and performance of the analytical method, 4) preparation of reagents, standards or calibrators, quality control materials, details of the analytical procedure, 5) full details of instrument maintenance protocols (when specific instrumentation is used), 6) methods for reporting of results and clinical interpretations, and 7) other pertinent data that facilitates effective an efficient execution of each procedure [31]. Uses of analytical tests should include diagnosis (with confirmation of clinical signs or symptoms), monitoring of treatment, prognosis assessment, disease detection, and other aspects of clinical care. Other important pertinent details presented at the end of the manual should include relevant literature references for methodology, clinical diagnoses, and further explanatory information of a technical nature.

Specific requirements to include in operation manuals for e-nose analytical instruments used in the laboratory depend upon the operational technology and procedures utilized for the analytical method employed and the particular types of analytes being detected. Most analytical methods require measurements of analyte concentrations, not just the presence or absence of specific analytes being detected. In molecular biomarker detection, the concentration of the analyte (quantitative detection) may not be as important as the presence (or qualitative detection) of particular chemical compounds within a clinical sample. The latter situation is usually the rule with e-nose instruments that generally are more effective at detecting biomarker analytes than determining the concentration of the biomarker. Each e-nose technology has various advantages and disadvantages relative to the capability of the instrument to detect specific classes of chemical analytes in the sample.

4.3. Virtual laboratories

Virtual laboratories (VLs) are simulators that help students to become more acquainted with analytical instruments, particularly new complex technologies, as well as instrument controls and operations either within the classroom or remotely [32]. The interest in VL teaching technologies is primarily due to the high cost of experimental laboratories. Distance learning allows a means of limiting costs for continuous training by in-house educational facilities and reducing the time spent in an educational laboratory outside of the workplace. Student access to remote instrument-equipped sites through computer networks provides a very useful solution to limit training costs without constraining educational opportunities. VL simulators do not expect to replace real live-instrument training, but yield opportunities for more preliminary experience via remote practice prior to direct experimentation on live-instrument systems. Thus, VLs can be powerful auxiliary didactic tools to facilitate considerable student instrument-training at relatively low costs. Since virtual systems are programmable, they can be used for multiple teaching applications without the need for dedicated instrumentation. The flexibility of VL systems allows instructors to adapt operations to specific student users and skill levels (competency, experience, and confidence) and to support different types of interactions between students and educators [32]. For example, advanced students can receive details of instrument components and procedures, measurement protocols and problems (accuracy, calibration, delays, sampling frequencies), and create their own experimentations with virtual or remote instruments. More than one simulation algorithm may be used to simulate complex measurements.

Some realized advantages of VL technologies are the ability to customize student exercises, validate test results which can be automatically performed, provide student access from anywhere at any time, achieve greater realism than with a simulation, optimize time consumption, minimize difficulties in assimilating the learning subject, maintain student safety (not in the presence of potentially dangerous apparatus without supervision), and control availability to lessons of greater difficulty (based on student progress), determined by a grading algorithm in the VL software [33]. Possible disadvantages may include the inability to provide the experience of direct physical contact with a real apparatus and physical connections limiting the development of operational skills. Another disadvantage is the absence of direct help via instructor supervision unless the instructor is present during use of the VL by the student. This lack of hands-on laboratory experience may foster loss of student intuition about the physical meaning and magnitude of instrument operations and outputs, precluding verification of instrument behavior to be sufficiently similar to simulated behavior [34].

4.4. Remote access laboratories

There are four main approaches that have been followed for remote teaching including: 1) web-based lectures and seminars, sometimes interactive, that help reduce start-up time for new didactic applications, 2) web support to university courses, including lessons and exercises, 3) simulation of actual experiments to be executed remotely or on the user's PC, and 4) remotely accessed laboratories (RALs), where students can access actual instrumentation remotely for instruction and various didactic experiences [35]. Remote access laboratories (RALs) systems, also known as virtual measurement systems, provide distance education and training opportunities in the operation of instrumentation and measuring devices [36]. These remote-controlled measurement systems consist of analytical instruments that are accessed from a distant location by students via computers or terminals through either networks or internet communication systems. RALs have the advantage of offering students invaluable experience and practice in the operation of analytical and measuring instrumentation without having to incur the expenses associated with live training by instructors. The frequent necessity of repeating the same instrument experience multiple times via RALs is an effective way to provide students with an opportunity to practice instrument operation without continuous supervision to assure that students gain competence and sufficient familiarity with complicated procedures often associated with new sophisticated equipment. In this way, student confidence can be built through impersonal remote practice that often avoids embarrassment that usually occurs in early stages of learning as a result of a lack of familiarity with instrument operations or insufficient practice needed to build proficiency.

The use of remote network and internet-based facilities for providing training-access to analytical and measuring instrumentation has made a huge impact on the effectiveness of measurement-related training, particularly in speeding up the training process through continuous student access to instrument-operation practice sessions [35]. RAL systems allow instructors to develop tailor-made training systems and tools for specific instruments with flexible instrument-customized teaching solutions and tasks for students of all levels of competencies and experience. RAL systems can be used to address teaching problems associated with instrument architecture, number and types of instruments to be connected to the system, and application-specific software designed to teach operational procedures for individual instrument types. Adapted software systems can be chosen and modified to address problems relating to multiple student access to the laboratory, logistics of connections among multiple servers, data integrity and formats during experiments, use of graphical user interfaces, and flexibility and scalability of experiments done with different instruments and lesson types.

4.5. Live instrument instruction

Student training by live-instrument testing with instructor supervision is usually the final step for training laboratory technical staff in the use of analytical and other measurement instrumentation. However, this stage of training and testing is the most important for it determines whether a student is certified as competent to use a specific laboratory device. There is no substitute for live training to assess and arrive at a final evaluation of a student’s operational proficiency which will largely determine the student’s official competency status for operating specific instruments in the clinical laboratory setting, an essential requirement for certification and employment. Even though RAL systems may be devised to allow interactions between students and instructors, some didactic demonstrations and instrument-user tips for students are more effectively communicated with live person-to-person interactions. Some examples of hands-on instructions that are not easily communicated remotely include teaching idiosyncrasies of individual analytical instrument operations, the so-called “knack” of techniques and procedures to achieve the most effective instrument performance to assure accuracy and precision of data outputs, and ways of speeding up instrument data output to improve efficiency in instrument operations and increase sample throughput. At larger teaching or university-associated clinical laboratories, live direct training and experimentation in the operation of real instruments is usually gained during laboratory training periods following preliminary remote practice if available, but many smaller clinical laboratories in rural communities may depend totally upon direct instrument training of technicians by experienced higher level laboratory technical staff.

5. Conclusions

Technical staff in the clinical laboratory must readily adapt to new developments, emerging diagnostic technologies, and required interdisciplinary skills by learning to exercise and continually update their education, skills, and increasingly complex roles in the ever-evolving clinical laboratory. The clinical laboratory of the future may have little need for low-level laboratory technicians representing types Level C and D defined by WHO because of the increase in need for highly skilled staff for all laboratory procedures. The increasing sophistication of diagnostic technologies and techniques viewed as complex today will not be considered so unusual in the future as technological advancements continue to accelerate at a rapid pace. Thus, the clinical laboratory technicians of the future will likely be challenged by the requirement to be trained in methods and the analytical instrument operation at ever increasing levels of complexity to keep up with rapidly expanding scientific advancements and knowledge that has led to such a plethora of new electronic-detection devices that have numerous applications in the modern clinical laboratory. Fortunately, the electronic-nose industry has now shifted its approach by designing e-noses that are smaller, less expensive, increasingly more application-specific (specialized), easier to use by operators, and that produce results more easily interpreted by laboratory technicians due to limited data outputs, built-in data analysis and data-interpretation algorithms that facilitate diagnostic assessments for patient treatment and management [37].

This paper provides a thorough guideline and review of some of the more important theoretical and practical considerations to include in the development of training courses to teach clinical laboratory technicians in the proper operation of e-nose devices. Prerequisite technical training and educational requirements of laboratory technicians, prior to e-nose operational training, are summarized to help assess the technical background and prior experience of each student. This information is useful for assigning and selecting training modules to fit individual students' training needs based on levels of difficulty and proficiency. Specific teaching recommendations are given in the areas of interactive teaching, use of procedural manuals, virtual and remote-access laboratories, and live instruction to help clinical technologists, and other individuals responsible for teaching clinical laboratory techniques, to produce effective teaching programs. These didactic methods provide a means for designing a thorough instructional course that includes all of the specific necessary elements needed for teaching the various laboratory skills needed to equip clinical technicians with the capabilities of operating electronic-nose devices with proficiency, and enabling them to generate consistently accurate and effective chemical analyses of clinical laboratory samples.

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